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Combustion of Hazardous Waste

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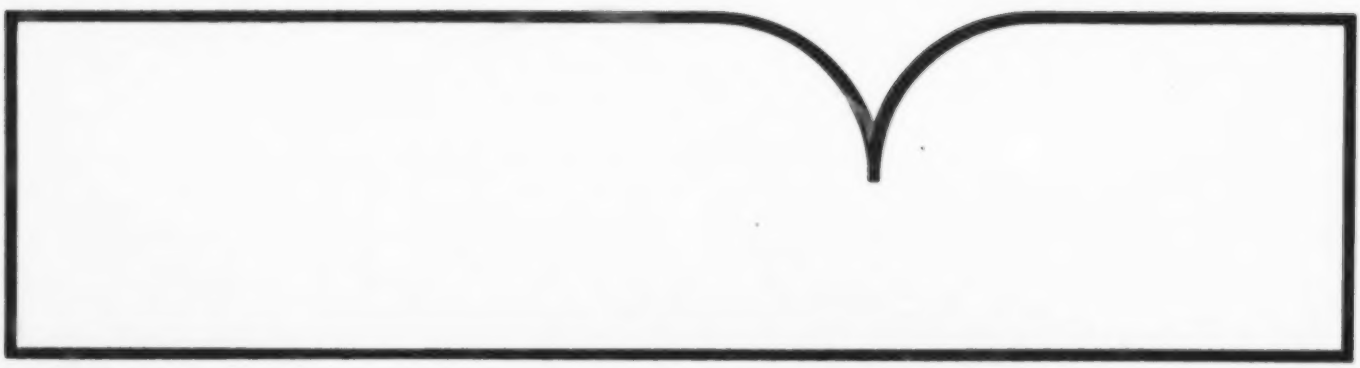

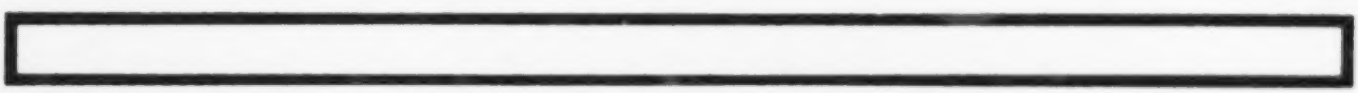

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COMBUSTION OF HAZARDOUS WASTE

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16. ABSTRACT

Of the 260 MMT of hazardous waste generated annually in the United States, 1.70 MMT are disposed of in incinerators, 3.50 MMT are burned in boilers and 0.35 MMT are burned in other industrial processes. This paper is an overview of the technologies that can be used to combust hazardous wastes. The paper describes the USEPA regulations that affect incineration. Technologies for accomplishing the combustion of both solids and liquids are discussed. The capabilities of industrial boilers to effectively destroy wastes are addressed. The advantages and disadvantages of the use of cement kilns for waste disposal are presented.

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COMBUSTION OF HAZARDOUS WASTE

Robert A. Olexsey

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) estimates that, in 1981, there were 260 million metric tonnes (MMT) of hazardous waste generated in the United States. From Table 1, we can see that this waste is managed in a variety of fashions. The numbers are based on notifications received by the Agency under the Resource Conservation and Recovery Act of 1976 (RCRA) and contain some double accounting. For instance, some wastes may be stored, then treated, and the residues subjected to disposal. Some wastes may go directly to disposal facilities. Under RCRA, EPA has promulgated separate regulations for treatment, storage, and disposal facilities (TSDFs). The principal disposal operations are underground injection (60 percent) and landfill (5.5 percent). Under RCRA, incineration is classified as a treatment technique. Table 2 describes the waste treatment technologies employed in 1981 (1).

As can be seen from Table 2, RCRA regulated incineration currently accounts for a small amount of total hazardous waste management in the United States. EPA estimates that 25 MMT of hazardous waste is capable of being incinerated. Therefore, there is significant potential for increased use of incineration as a hazardous waste disposal practice in the United States. In addition to the 1.70 MMT of hazardous waste incinerated under RCRA, 3.50 MMT of industrial wastes are burned in about 1300 industrial boilers and 0.35 MMT are burned in other industrial processes such as cement kilns. Under RCRA, the wastes currently disposed of in boilers and industrial processes are considered fuels and not subject to existing RCRA regulations. Incineration and combustion in boilers and industrial processes will be discussed in later sections of this paper (2).

EPA REGULATIONS

On January 23, 1981, EPA promulgated regulations for the incineration of RCRA hazardous wastes. These regulations state:

- A destruction and removal efficiency (DRE) of 99.99 percent must be achieved for each principal organic hazardous constituent (POHC) designated in the waste stream.

TABLE 1. HAZARDOUS WASTE GENERATION AND MANAGEMENT (1981)

	QUANTITY (MMT)	VOLUME (BILLION GALLONS)	NUMBER OF FACILITIES
GENERATION	260	71	4818
MANAGEMENT			
STORAGE	134	36.5	4299
DISPOSAL	54	14.7	430
TREATMENT	176	47.5	1494

TABLE 2. HAZARDOUS WASTE TREATMENT (1981)

	QUANTITY (MMT)	VOLUME (BILLION GALLONS)	NUMBER OF FACILITIES
SURFACE IMPOUNDMENTS	62	16.6	410
TANKS	32	8.73	609
INCINERATORS	1.7	0.45	240
OTHERS	17	4.48	372

- Particulate emissions may not exceed 180 mg/dscm (0.08 grains/dscf) for a stack gas that contains 7 percent oxygen or is corrected to 7 percent oxygen.
- Stack emissions of hydrogen chloride (HCl) must be no greater than the larger of either 1.8 Kg per hour (4 lb/hr) or 1 percent of the HCl in the stack gas prior to entering any air pollution control equipment (3).

A POHC is a substance which is listed by EPA as a hazardous waste in Appendix VIII of the Federal Register (40 CFR Part 261, May 19, 1980) or a waste which is determined to be hazardous because it fails one or more of EPA's waste characteristic tests (ignitible, toxic, corrosive, reactive). For wastes which are made up of only one hazardous component, the single compound is the POHC. For mixtures of compounds, EPA provides guidance that recommends selecting as POHCs those compounds which are present in the waste in the highest concentration and also those compounds which are the most difficult to destroy through incineration. For cases where data on "incinerability"

(degree of difficulty of achieving the 99.99 percent DRE) is lacking, EPA recommends using the compound unit heat of combustion (ΔHC per molecular weight) as an incinerability ranking procedure (the higher the ΔHC/MW, the easier the compound is to destroy) (4).

EPA's regulations provide for certain exceptions to the incineration standard. Wastes that are hazardous solely due to the characteristic of ignitibility are exempt from the regulations. Certain military reactive waste that possess no toxicity characteristics are also exempt from the regulations. Finally, as stated previously, wastes that are burned in any device that functions primarily to produce energy are considered fuels, not RCRA hazardous wastes, and are exempt from the incinerator requirements. EPA is considering regulations for these boilers and industrial thermal processes. The Agency has issued guidelines that will help permitting officials determine if a given thermal operation is, indeed, a legitimate energy production process, or merely a "sham" to evade the regulations. These guidelines deal with fuel value of the waste, the disposition of the energy produced, and the ratio of waste to primary fuel in the combustor.

EPA has proposed a regulation for limitation of hazardous combustion by-products, or products of incomplete combustion (PICs) but the proposal has not been finalized. In addition, RCRA regulations require minimum operating controls such as preheating the combustion chamber with fossil fuel before waste is introduced, automatic waste cut-off in the case of combustor "upset", and continuous monitoring of carbon monoxide, flame activity, and combustion gas temperature. Exact control parameters for each individual facility are determined during the permitting process and most often established through a trial burn.

Incineration of polychlorinated biphenyls (PCBs) is regulated under the Toxic Substances Control Act (TSCA). These regulations require a destruction efficiency of 99.9999 percent. In addition, design specifications for burner operation are imposed. A combustion temperature of 1200°C and a gas residence time of 2 seconds are required (5).

Burning of wastes at sea in ocean-going incinerator ships is regulated per international agreement (6). Current requirements are for a 99.9 percent destruction efficiency but any permits that may be granted most likely will require performance equivalent to RCRA provisions for POHC destruction. The ships do not have air pollution devices and could not operate if requirements are imposed for HCl control.

U.S. INCINERATION PROFILE

Incinerator facilities in the United States are predominantly privately owned with a few facilities operated by the military and very few publicly owned and operated hazardous waste incineration plants. Seventy-seven percent of the operating facilities handle only wastes that are generated on-site. Such incinerators are located at manufacturing or processing facilities and are dedicated to handling only wastes generated by the facility. The bulk of the remainder are commercial facilities that accept, for a disposal fee, wastes from a

variety of generators. All incinerators, whether commercial, private, off-site, or on-site, must comply with the incinerator regulations that were described in the preceding section of this paper.

Seventy-nine percent of the incinerators handle liquids only while 11 percent are designed for bulk wastes and can accommodate both solids and liquids. Ten percent of the units are special purpose incinerators dedicated to radioactive, military, biological, or other type wastes.

Table 3 describes the major waste streams incinerated in the United States in 1981. The Waste I.D. Numbers are derived from EPA's system which categorizes wastes by characteristics and/or industrial process source (7). Wastes considered ideal for incineration are ignitible, nonhalogenated, nonaqeous liquids which have low ignition temperature and little propensity to form hazardous combustion by-products. Alcohols and spent nonhalogenated solvents are examples of wastes which are excellent incineration candidates.

The incineration industry is fairly well established in the United States. In 1982, there were 57 companies actively marketing incinerators, with 28 companies actually having sold units. In addition to the 240 incinerators operating in the United States in 1982 there were 40 units under construction. About one-half of the operating units and almost all the units under construction have air pollution control systems. Almost one-quarter of the operating systems practice heat recovery of some type. Of the total number of incinerators in operation, 64 percent were of the liquid injection type, 17 percent were fixed hearth, 12 percent were rotary kiln, 3 percent were fluidized bed, and 2 percent were multiple chamber hearth. Almost all the facilities under construction were liquid injection, rotary kiln, or combination liquid/kiln facilities (8).

INCINERATION TECHNOLOGIES

The five hazardous waste combustion approaches which have the most significance from a current and/or potential application perspective will be discussed here. The five technologies are those presented in Table 4, namely liquid injection, rotary kiln, at-sea, industrial boilers, and cement kilns. There are many other combustion approaches that appear to have the ability to achieve acceptable waste destruction, but, at least in the short run, are likely to have less applicability than those described in Table 4. Technologies that have promise for hazardous waste application, either generally or for specialized wastes, include the fluidized bed, starved air or pyrolytic approaches, and other industrial processes such as lime kiln and brick making furnaces. Some or all of these approaches have been tested (or will be tested) by EPA and have been found capable of destroying wastes.

LIQUID INJECTION

Figure 1 is a block diagram for a liquid injection incineration system. The most common type of combustion units marketed today are the horizontally and vertically-fired units as depicted in Figures 2

and 3. The two configurations are basically similar in operating conditions.

The liquid injection incinerator is confined to hazardous liquids, slurries, and sludges that have kinematic viscosity of 770 SSU or less. The liquid waste must be converted to a gas prior to combustion and this change is brought about by changing the waste surface area through atomization. If the kinematic viscosity exceeds 750 SSU, the atomization may not be fine enough and droplets of unburned liquid may leave the incinerator. An ideal size droplet is about 40 micrometers or less and is attainable mechanically by using rotary cup or pressure atomization or via gas-fluid nozzles and high pressure air or steam.

The combustion chamber is a refractory lined cylinder. Burners are normally located in the chambers in such a manner that the flames do not impinge on the refractory walls. The combustion chamber wall can be actively cooled by process air prior to its entry into the combustion zone, thus preheating the air to 150°C to 370°C. Afterburners may be used on the flue gas but are generally not required when the wastes have a sufficiently high heating value. In the case where a number of wastes are burned, conventional practice is to blend wastes prior to introduction into the combustion chamber to maintain a relatively constant feed into the chamber.

The key to efficient destruction of liquid hazardous wastes lies in minimizing unevaporated droplets and unreacted vapors. As in any combination operation, the optimization of temperature, residence time, and turbulence is critical. Liquid injection incinerators are variable dimensionally and have feed rates of up to 5600 L/hr.

Application of air pollution control processes depends on operating characteristics of the components or devices, the physical/chemical characteristics of the waste to be treated, and the emission standards imposed by regulations. For clean spent nonhalogenated solvents, it is possible that minimal or no air pollution control may be required. For materials that contain chlorine or dissolved solids, removal of HCl and particulate emissions may be achieved through use of high energy venturi scrubbers, ionizing wet scrubbers or, if HCl has been removed or is not present, electrostatic precipitators (ESPs). Particularly in acid gas situations, corrosion and erosion are problems and the use of acid resistant tile liners, polymeric liners, and Inconel 625 are commonplace. Caustic solutions are used to reduce the acidity of the gas and liquid in the air pollution control system.

The advantages of liquid injection incineration are that it is capable of accepting a wide range of liquid hazardous wastes; it requires no continuous ash removal system other than for air pollution control; it possesses a fast temperature response to changes in the waste fuel flowrate; it has virtually no moving parts; and has relatively low maintenance costs. Its limitations are that it can only accept wastes that can be atomized through a burner nozzle; supplemental fuel must be provided if heat content of the waste is insufficient to maintain ignition temperature; and the burners are susceptible to pluggage (9).

TABLE 3. MAJOR WASTE STREAMS INCINERATED (1981)

WASTE TYPE	WASTE I.D. NO.	NUMBER OF INCINERATORS	QUANTITY INCINERATED (THOUSAND MT/YEAR)
Ignitible Organic Liquids	D001	69	36
Contaminated Water	D001	19	127
Corrosive, Reactive	D002, D003	32	175
Spent Halogenated Solvents	F001, F002	18	16
Spent Nonhalogenated Solvents	F003	22	212
Acrylonitrile Bottoms	K011	3	109
Hydrocyanic Acid	P063	6	123
39 Other Waste Streams	-	-	107

TABLE 4. OPERATING RANGES OF HAZARDOUS WASTE COMBUSTION PROCESSES

PROCESS	TEMPERATURE RANGE (°C)	RESIDENCE TIME
Liquid Injection	650 to 1600	0.1 to 2 seconds
Rotary Kiln	820 to 1600	Liquids and gases, seconds; solids, hours
At-Sea	1350 to 1470	0.1 to 2 seconds
Industrial Boilers	870 to 1430	0.1 to 3 seconds
Cement Kilns	1400 to 1650	Liquids and gases, seconds; solids, hours

The U.S. EPA has conducted a number of field tests of operating liquid injection facilities and has found that, generally, the units have achieved the DRE required by the RCRA regulations. Particulate emission reductions, especially in jurisdictions that have lower standards than the Federal requirement, have been more difficult to achieve.

ROTARY KILN

Rotary kiln incinerators are generally refractory-lined cylindrical shells mounted at a slight incline from the horizontal plane.

Rotary kiln systems are used to degrade solid and liquid combustible wastes, but combustible gases may also be oxidized. Figure 4 is a schematic of a rotary kiln system.

Solid wastes, sometimes packed in fiber drums, are fed into the kiln, generally by conveyor. Liquids and sludges are pumped in, with liquids usually being strained, then burned in suspension by atomization with steam or air. The kiln and liquid burner are equipped with gas or oil burners for initial refractory heating, flame stability, and supplemental heat if necessary. Rotary kilns currently manufactured in the United States include both cocurrent (burner at the front end with the waste feed) and countercurrent (burner at the back end) types. Optimal length-to-diameter (L/D) ratios range from 2 to 10 and rotational speeds of 0.3 to 1.5 m/min are common, depending on the nature of the waste. Residence times vary from a few seconds for a highly combustible gas to a few hours for a low combustible solid waste. A typical feed capacity range is 600 kg/hr to 2000 kg/hr for solids, and 630 L/hr to 2250 L/hr for liquids at temperatures ranging from 800°C to 1200°C.

After leaving the kiln, the flue gas enters a secondary combustion chamber that contains an afterburner. Gaseous or liquid fuels are used to generate a high-temperature oxidizing environment in order to ensure a complete destruction of organic vapors. Afterburners are generally of the direct flame type which pass the fuel gas directly through a flame zone. However, afterburners may be of the thermal type in which the flue gas flows through a high temperature zone, or of the catalytic type which incorporate a catalytic surface to accelerate the oxidation of uncombusted gas constituents. Temperatures ranging from 650°C to 1300°C are generally required for successful operation of afterburners. Depending on the type of pollutant in the gas stream, residence times may range from 0.2 to 2.0 seconds. To ensure good mixing, afterburners are operated at high velocity gas flows, ranging from 8 to 15 m/s. A typical afterburner will be 10 m long, 4 m high, and 4 m wide.

Due to the nature of the feed material, air pollution control requirements are more severe for rotary kilns than for liquid injection units. High energy venturi scrubbers, ionizing wet scrubbers, or wet ESPs are required to reduce particulate emissions to acceptable levels (10).

EPA has conducted field tests of operating rotary kiln incinerators and found them capable of achieving the required destruction and removal efficiency for organics. Particulate emissions have presented a problem and some facilities were not in compliance with the Federal standard.

A common configuratin for large commercial incineration facilities is to have separate rotary kiln and liquid injection units firing into a common afterburner. In this case, the afterburner is of the unfired thermal type with the heat supplied by the liquid injection incinerator.

The main advantage of the rotary kiln is its feed flexibility. The main disadvantage of the rotary kiln is its relatively low thermal efficiency.

AT-SEA

Incineration at sea is a commercially viable process. There are currently two ships operating in Europe. Ships have operated intermittently off the United States Gulf Coast burning specialized wastes. One ship has applied for a permit for continuous operation off the United States coast and at least two United States ships are under construction.

Incinerator ships are, in essence, large floating liquid injection incinerators. The ships consist of crews' quarters, storage tanks, and incinerators. The ships generally have two or three incinerators. Unit incinerator sizes can be as much as 50 percent larger than the largest land based liquid injection incinerators. A single ship can handle as much as 6000 metric tons of liquid hazardous wastes per voyage.

The incinerator ships do not use flue gas scrubbers, even for highly halogenated wastes. The premise behind the absence of scrubber is that the plume will touch down in the ocean and the sea water will serve as a buffer for the acid gas. If the incinerator ships were required to incorporate scrubbers, the cost advantage they accrue due to their larger capacities than land based units would be diminished. Incinerator ships require, of course, shore based facilities for collecting, storing, and loading the wastes.

The U.S. EPA has conducted performance tests during a number of waste burns. Waste destruction efficiencies (DEs) were found to be equivalent to those achieved by land based incinerators.

The main advantages of at sea incineration are the large waste handling capacities, low unit disposal costs, and the alleviation of incinerator siting problems by removal of the burn site from land. Disadvantages include the inability to handle solids and sludges, the need for the shore facilities, and the lack of HCl control.

INDUSTRIAL BOILERS

There are over 240,000 industrial boilers in the United States. Under current U.S. EPA RCRA regulations, hazardous materials could be burned in any of these boilers without being subject to the incinerator performance standards. More likely to be used for waste disposal are the over 5,500 boilers that have heat production capacities of 1.0 x 10^{10} joules/hr (10^{7} Btu/hr) or greater in the chemicals, petroleum refining, and paper industries.

Boilers that have been or could be used for hazardous industrial waste disposal include small firetube gas- or oil-fired units in the 1.0 to 5.3 x 10^{10} joule/hr (10 to 50 million Btu/hr) range, package gas- or oil-fired watertube units in the 5.3 to 15.8 x 10^{10} joule/hr range (50 to 150 million Btu/hr), and large field erected oil or coal

boilers larger than 15.8×10^{10} joules/hr (150 million Btu/hr). Wastes that are fired generally are liquid wastes that are generated on the site of the facility (or plant) that contains the boiler. Wastes that are burned include alcohols, spent nonhalogenated solvents, and highly volatile by-products which may be gaseous when introduced into the boiler.

For the smaller boilers with only one burner, conventional practice is to premix the primary fuel (oil) and the waste material in a tank prior to introduction into the firebox. For larger boilers with multiple burners, one or more burner is dedicated to waste introduction with the remaining burners fired with primary fuel and used for leveling.

Waste may constitute over 50 percent of the fuel to the boiler for particularly clean, high energy value wastes. However, generally, the waste feed rate is below 20 percent of the total fuel to the boiler. For difficult to burn wastes and, particularly for corrosive halogenated wastes, feed concentrations below 5 percent (on a volume basis) are most common.

Small industrial boilers (less than 15.8 x 100 joules/hr) in the United States are not currently subject to Federal air pollution control regulations. Therefore, most industrial gas- or oil-fired boilers do not have air pollution control devices. Larger pulverized coal-fired boilers do generally have ESPs for particulate control. Smaller stoker-coal boilers may have mechanical cyclone collectors for large particles. Some boilers which are specifically designed to fire halogenated wastes may have wet scrubbers but there are very few, if any, industrial boilers which fire waste on a retrofit basis that have such control devices.

As part of its process to determine if a Federal regulation is required for boiler disposal of hazardous wastes, EPA has conducted field tests of several operating facilities. Generally, the tested boilers have achieved performance in the vicinity of 99.99 percent DRE, not quite as good as incinerators, but not as bad as the Agency feared at the outset fo the test program. Emissions of products of incomplete combustion from boilers, as might be expected due to the reaction product quenching in the superheaters and through the steam tubes, have been 5 to 20 times higher than emissions of principal organic hazardous constituents from the boilers (11).

The greatest advantage of boiler disposal is its reduced cost to the waste generator over either onsite or offsite incineration. Besides realizing the fuel value of the waste, the generator appreciates a sizeable opportunity cost savings from not having to dispose of the waste material in a RCRA regulated process. Also, the waste material does not have to be transportated, at some environmental risk, to a waste disposal site, which, under RCRA, prolongs the waste generator's liability for the waste material.

The biggest disadvantage of boiler disposal is the fact that the process is not regulated and may be prone to abuse by operators. It also deprives incinerator operators of a prime fuel material and may

contribute to an increase in the cost of commercial incineration of RCRA hazardous wastes.

CEMENT KILNS

Figure 5 is a schematic of a cement kiln operation that describes how waste material may be burned along with a primary fuel. In this arrangement, which is a wet process kiln, the cement making raw materials are fed into the top (left) of the kiln and exit at the bottom (right) as cement clinker. The burner is located at the lower end of the kiln. The fuel and the waste are ignited. The hot gases travel up the kiln, thereby heating the cement raw materials, exit the kiln, and are then cleaned in a baghouse before being exhausted through a stack. When waste is fired, any ash that is produced becomes part of the cement product.

Kiln lengths range from 18.3 to 231 meters (60 to 760 ft) with diameters from 1.8 to 7.6 meters (6 to 25 ft). Charge retention time in the kiln ranges from 1 to 4 hours. Gas retention time is approximately 10 seconds. Gas temperatures will typically reach a maximum of 1650°C.

There is ample opportunity to employ cement kilns as disposal vehicles in the United States. The United States cement industry has 158 plants and 342 operating kilns. Plant capacities range from 50,000 to 2,200,000 tonnes per year of cement product. Plants tend to be located near large population centers and, therefore, close to the sources of waste generation. Unlike boilers, however, cement kilns are not located on the premises of the waste generator and the waste must be transported off site for disposal. There is significant economic incentive for a kiln operator to accept wastes for disposal. Besides obtaining a fee for disposal of the wastes, the operator can offset some of the 33 to 40 percent of the total cost of cement manufacture that is attributed to energy demand.

Cement kilns generally have efficient air pollution control devices to control particulate emissions that are generated in the kiln. These devices are generally baghouses or ESPs. Very few wet scrubbers are used in the industry today. However, like boilers, kilns are extremely sensitive to high chlorine contents which must be kept below 3 percent for the sake of kiln and product integrity.

EPA has conducted several tests of operating kilns that burn hazardous waste materials. While more sensitive to adherence to proper operating conditions than first believed, the kilns were found to perform at least as well as boilers. A key factor that serves to police kiln disposal is the fact that temperatures in the kiln must be adequate to produce the cement product.

The advantages of kiln disposal are similar to those for boiler disposal. However, while the combustion process, itself, is not regulated at the Federal level, the transport and storage processes are subject to EPA RCRA regulations. Due to their numbers and their capacities, cement kilns have tremendous potential for contributing to solution of the hazardous waste problem (12).

CONCLUSIONS

Less than one percent of the hazardous wastes generated in the United States are managed by incineration. Nearly 15 times more wastes could be incinerated than is currently managed through incineration. Approximately three times more wastes are burned in unregulated industrial processes than are managed in RCRA regulated incinerators.

Combustible hazardous wastes are amenable to destruction in a wide variety of combustion processes. Most combustion processes have been found capable of performing in compliance with the EPA performance regulation for incinerators. At-Sea incineration and cement kiln incineration have considerable potential to handle large volumes of hazardous wastes.

The trend will be toward increased utilization of combustion as a waste management technique as more wastes are prohibited from landfills. The trend will be accelerated by recently enacted Federal legislation which bans specific wastes from landfills altogether.

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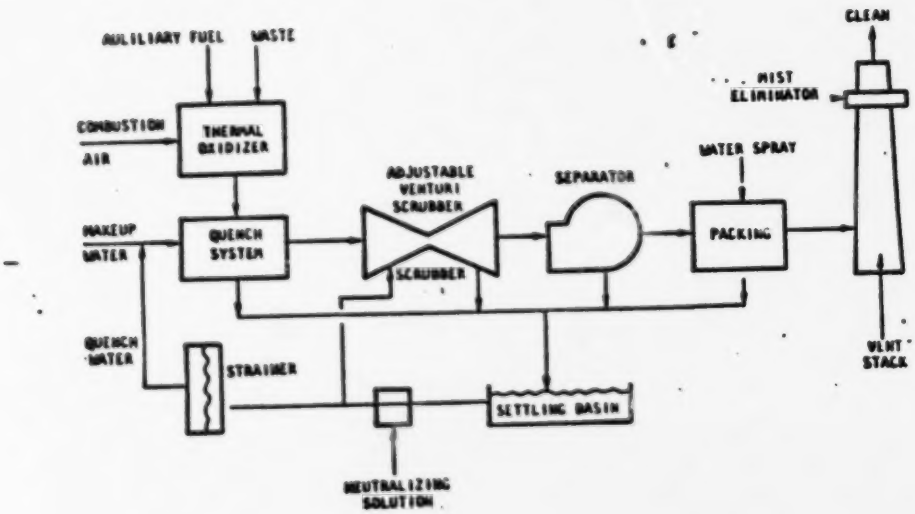

FIGURE 1. LIQUID INCINERATION SYSTEM

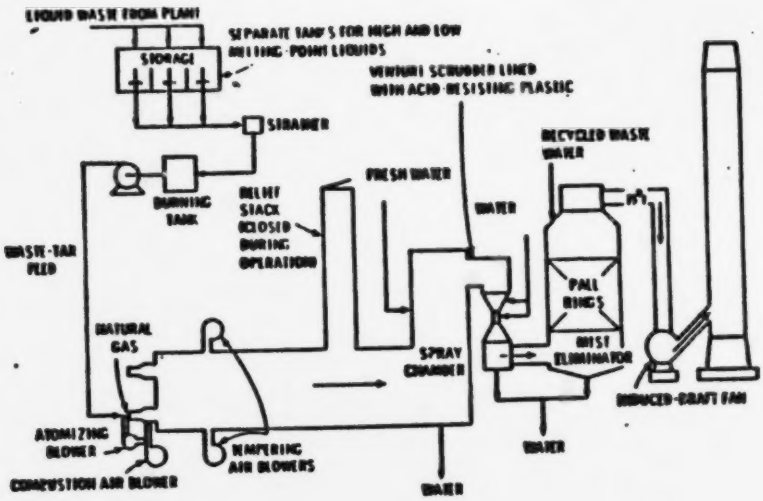

FIGURE 2. HORIZONTALLY-FIRED LIQUID INJECTION INCINERATOR SCHEMATIC

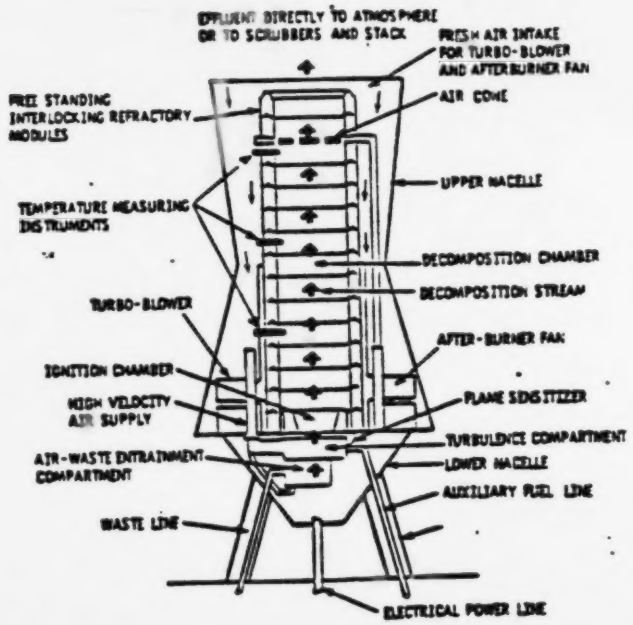

FIGURE 3. VERTICALLY-FIRED LIQUID INJECTION INCINERATOR SCHEMATIC

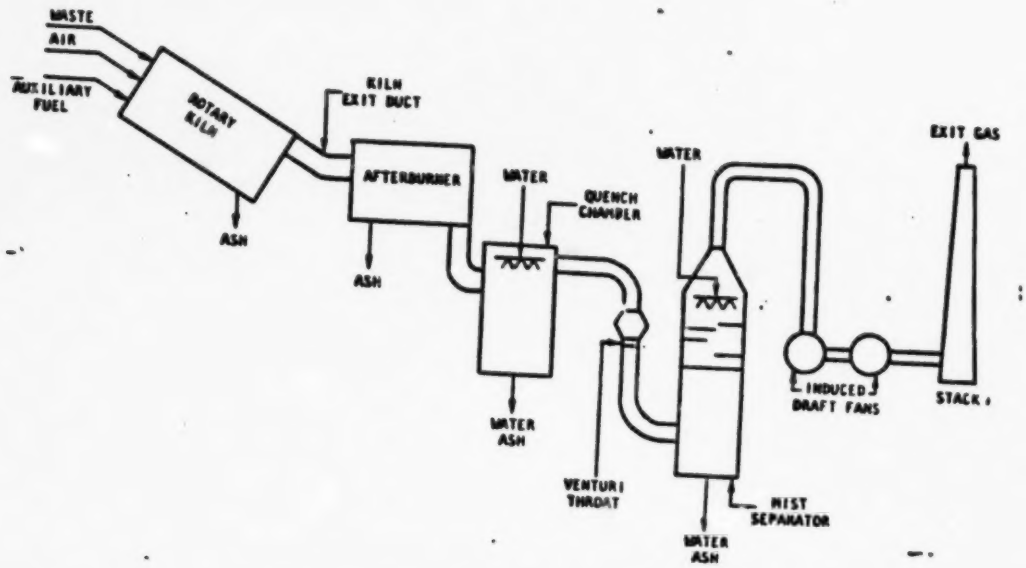

FIGURE 4. SCHEMATIC OF A ROTARY KILN TYPE INCINERATION SYSTEM

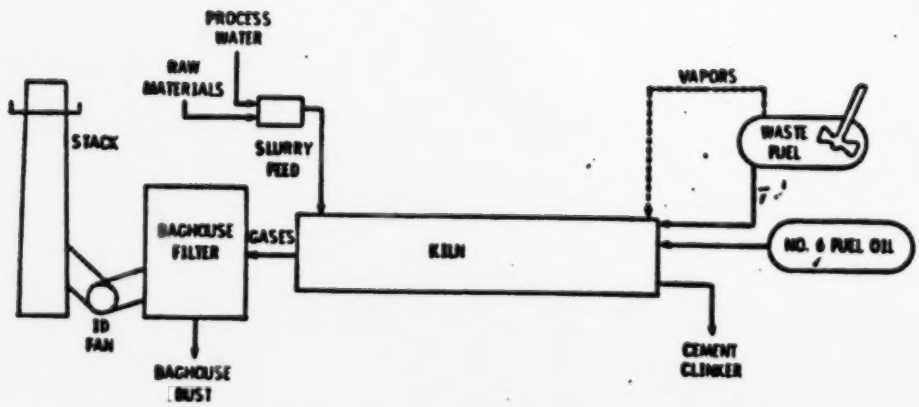

FIGURE 5. SCHEMATIC OF CEMENT KILN FIRING WASTE